

An Example of the Integration of Thermal Simulations into an Existing HVAC Course

RICHARD K. STRAND, PH.D.

School of Architecture, University of Illinois at Urbana-Champaign

Abstract

The form and communication of architectural education in the United States has begun a gradual shift into the electronic arena. While sketching and visualization will always be a part of the development of any architect, computer usage and literacy are becoming an increasing part of the educational process. Clearly, there are advantages as well as disadvantages to the digitalization of the educational process. While it requires more knowledge and aptitude on the part of the students and may lead to lack of understanding about the “real world”, the potential benefits are tremendous. One area in which computer usage can provide a more rounded and integrated educational approach is in the area of thermal simulations. Advances in computer capabilities, simulation programs, and interfaces make it possible to prepare students for the challenges inherent in the energy aspects of their designs and develop in them an intuition for the thermal aspects of buildings. This paper presents ways in which simulation can be used to reinforce the fundamental concepts in thermal physics and train students in the use of simulation programs as a means of enhancing the design process. Examples of projects focusing on envelope or “skin” related factors are presented.

Introduction

When one compares the typical studio environment at the university level today with the environment found 15-20 years ago, one finds that the surroundings have changed in at least one significant way—the availability and access to computers and their associated applications has increased significantly from virtually zero to at least a threshold level at most universities. These changes are mirrored somewhat in the level of computer competence and interest of the students. While not all studio courses use the computer and there is certainly the potential for misuse or over reliance on digital techniques, the computer can provide a platform for more in-depth analysis and understanding of buildings.

Computer simulation programs offer students more details about their designs and a better understanding of the impact of their design decisions. Visualization software allows students to quickly place their building designs in context with respect to their ideas and the surroundings of the building. Lighting and shadowing programs allow students to grasp the aesthetic affects of window placement, shading elements, and building geometry, orientation, and location. Construction software can assist the students in the development of sound foundational and structural system concepts.

Certainly, simulation software can be misapplied and an understanding of the results can be lacking. Nevertheless, the benefit of these programs is that they allow more complex analysis of building designs than would be possible with more traditional techniques. Software can perform detailed calculations quickly for a large number of cases that would be difficult and time consuming with hand calculations. Thus, the use of computer software in the design process can, in theory, lead to a more thorough understanding of how buildings work overall and also how to collect the many aspects of a building together into a seamless, integrated design.

Another area of buildings where software can be used to avoid excessive and tedious hand calculations, many of which are of limited accuracy, is the subject of thermal physics or thermal load calculations. If thermal physics and environmental effects are taught, these courses tend to focus on “rules of thumb” and general guidelines that usually have restricted applicability. Questions such as “should this building utilize passive solar design techniques and, if so, which ones?” can be difficult to answer for specific design situations without a good understanding of the thermal response of a building to environmental effects and the ability to perform even simple thermal simulation experiments. However, with the ability to perform thermal analyses on buildings using computer software, there is the possibility to investigate various design options quickly and integrate energy concerns into the design process.

Once the premise that thermal simulations are possible, can assist the design process, and enhance the educational experience of students is accepted, the focus shifts to the task of actually building thermal simulations into the course framework of a curriculum. One can argue that a rigorous and complicated task such as building thermal simulation cannot be taught overnight and that only a semester long course can be of lasting value to the students. Admittedly, there is a significant amount of validity to this argument and true mastery of thermal simulations requires a substantial amount of instruction time. Unfortunately, most architecture curricula are already filled to capacity with design, history, structures, technology, and general education courses.

There are alternatives to the semester long thermal simulation course. One alternative is to follow the “continuing education” pattern. In a one-week course, a sizeable amount of progress can be made in the teaching of building simulation software. While this tends to be an attractive option for practicing professionals, most students are neither drawn to nor have the extra resources for such a course that is over and above their regular coursework.

Another alternative to the semester long course is to spend a brief amount of time in a related existing class exploring the use of thermal simulations. An introductory level class dealing with HVAC and associated issues is one course where the topic of thermal simulations can be addressed without significantly modifying the course outline. In such a course, issues such as building envelope, environmental effects, internal heat gains, and the resulting heating and cooling loads are typically covered in some detail. Introducing thermal simulation to the course can enhance the discussion of these issues and in particular the discussion of the heating and cooling loads.

In general, the discussion of heating and cooling loads for a building will tend to center on a hand calculation technique. This is understandable since it can be used to teach some of the basic thermal physics that are present in a building and how different environmental effects will impact a building from a thermal perspective. Yet, the hand calculations themselves have built-in assumptions and in many cases significant flaws that lead to inaccurate results and potential misunderstanding of the environmental impact of a building. In discussing some of the limitations of the hand calculation methods, it is possible to provide thermal simulations as an alternative that corrects some of the flaws of the hand calculations. Thus, the introduction of thermal simulations or the concept of using thermal simulations can be naturally introduced at varying levels of detail.

While no simulation program is “perfect”, the programs do provide an opportunity to improve on the thermal load predictions. Discussing the differences between the methods used in the hand calculation and the thermal simulation can lead to a better understanding of the underlying physics that governs the thermal processes as well as an appreciation of simulation programs and their capacity to analyze situations quickly and accurately. For example, hand calculations use film coefficients when determining heat transfer through building surfaces. While the intent is to capture the convection and radiation from the surfaces to their surrounding environments, the film coefficients are developed for very limited conditions and thus can introduce inaccuracies into the calculations. Discussion of the limitations of film coefficients can eventually lead to a discussion of more accurate representations of heat transfer that are used by simulation programs. In fact, exercises using simulations can even be constructed to identify the relative error associated with the use of film coefficients.

Courses dealing with thermal simulations already exist in a variety of formats at many universities at both the undergraduate and graduate level. This paper is an effort to document attempts to link thermal simulation with an existing introductory HVAC course. The goal of introducing simulation into the course was not an attempt to rewrite the class objectives but rather to expand upon the course outcomes and prompt student interest in using thermal simulations in their studio projects.

Simulation Usage and Goals

The slight reorganization of the introductory HVAC class began with a realization of the coming change within ASHRAE toward a heat balance based approach for thermal load calculations. One of the advantages of the heat balance based approach, besides the promise of increased accuracy of results, is that it provides a good framework for introducing how a building is affected by thermal environmental forces and how those elements lead to the building thermal response. Another advantage is that computer software already exists that is based on the heat balance method. Thus, by reorienting the discussion of heating and cooling loads to a heat balance framework, the course can teach the same topics as before and also present the basis for the computer software.

The simulation program and interface being used for the course described in this article are BLAST and HBLC, respectively. BLAST (Building Loads Analysis and System Thermodynamics) is a heat balance based thermal load and energy analysis program. It began development in the 1970s and has been enhanced steadily since the release of Version 3.0 in the early 1980s. One of the more significant improvements to the BLAST family of software in the 1990s was the addition of a graphical user interface known as HBLC (Heat Balance Loads Calculator). HBLC replaced a text-based menu-driven program that was intended for non-Windows environments. HBLC provides a relatively friendly environment to create input files for, run, and obtain output information from BLAST.

Through a series of computer laboratories and two homework assignments, the introduction of the BLAST/HBLC component to the introductory HVAC course has sought to meet several objectives including:

- Show how the basic assumptions made for peak heating and cooling load calculations impact the hourly thermal load profiles one might expect to see
- Gain an appreciation for the significance of thermal mass on the “skin” thermal loads
- Realize the importance and purpose of defining proper thermal zones

- Witness the impact of control methods on the hourly cooling loads
- Begin acquisition of basic thermal intuition through simple case studies
- Develop a limited understanding of the basics of thermal simulation
- Demonstrate the relative ease of using computer based simulations in comparison to tedious hand calculations

While these goals have remained consistent throughout the past five semesters of teaching this course, the selection of buildings and the method for achieving these goals has changed somewhat. Part of the change is due to limits on time and a shrinking of resources available to perform the simulations. Most of the change is due to the experiences of the previous semesters.

In the first three semesters, an attempt was made to use data from an actual building to give the simulation projects a feeling of reality. In any “real” project, there are significant obstacles to overcome and important decisions that have to be made. Sometimes, the process of overcoming these obstacles can be very instructive. Figure 1 shows the floor plan of the building that was used in the first three semesters in which simulation was taught as part of the introductory HVAC course.

(insert Figure 1 here)

Figure 1. Fort Monmouth Education Center (BLAST Support Office).

While the use of this building taught important concepts such as thermal zoning and gave the homework problems a realistic touch, the students spent more time struggling with the input of geometry and other features of the building. Though learning those things is important to eventually having a good grasp of using any simulation program, it was decided that this was beyond the scope of what one could reasonably expect considering the main goals stated above and the fact that the students spent less than 10 hours of supervised time in the computer laboratory.

With a reduction in supervised computer laboratory time to approximately 6 hours occurring in the fourth semester, there was the realization that the complex building attempted in the first three semesters would simply overwhelm the students and cause the more important goals of the simulation work to go unfulfilled. Thus, a fictional building plan was developed to reduce the complexity of the building while still having some elements of interest for the students. Figure 2 shows a typical floor plan for the multi-story building used in the Fall 2000 semester.

(insert Figure 2 here)

Figure 2. Fictional Multi-Story Office Building with Articulated Exterior.

Even with this relatively simple geometry, it was quickly discovered during the first computer homework problem during the computer laboratories that this geometry was still too complex to adequately achieve the main goals of the thermal simulation usage. Part of these difficulties was related to frustration with attempting to run the software over a campus network. This caused numerous problems with the software that would not normally be encountered. This was resolved for the second homework problem by providing a base version of the file with all of the geometry features already set.

In the most recent semester (Spring 2001), it was determined that further simplification was necessary to completely avoid geometry issues. Figure 3 is the very basic “Rubik’s cube” type floor plan that was used. One disadvantage to the plan as shown in Figure 3 is that the thermal zoning has already been defined. While this still allows discussion of thermal zones and their importance, there is a slight loss of appreciation for the fact in many cases thermal zones are only approximations and not exact geometrical representations. However, though the exterior and interior geometry appears to be overly basic, it still allows for investigation of a host of issues including building/zone orientation while representing a form that could be typical of many multi-story office buildings. In addition, all of the difficulties with modeling the geometry within the interface were eliminated, allowing for more understanding and useful interpretation of thermal simulation results.

(insert Figure 3 here)

Figure 3. Fictional Multi-Story Office Building with “Rubik’s Cube” Floor Plan.

Results and Analysis

Despite the refinement of the building geometry that occurred over several semesters, the basic assignments remained the same. The first three goals mentioned in the previous section are achieved in the first homework problem. It asks the students to enter the building being investigated into HBLC as a single zone and run the resulting model with BLAST. With a simple one-zone model, the students can clearly see the basic form of the thermal loads: the heating load is constant at the peak level while the cooling load varies significantly throughout the day. This relates back to the assumptions typically made for heating and cooling loads and thus reinforces the

concepts learned during lectures. Figure 4 shows some sample results for the building shown in Figure 3 (skin loads only; i.e., no internal gains).

(insert Figure 4 here)

Figure 4. Skin Loads for Winter and Summer Design Days for the Figure 3 Building.

After observing the results for the “base case” building, the students are asked to redefine all exterior surfaces as walls with the same thermal resistance but with all of the thermal mass removed. This is equivalent to assuming steady state heat conduction through all of the exterior surfaces. Since the peak heating load calculation is a steady state calculation, the obvious result is that there is no difference between the cases with and without thermal mass. For the summer design day, there is a significant difference in the skin cooling load as shown in Figure 5. This again reinforces lecture discussions and also brings the realization that thermal mass is an element of a building design that impacts its thermal response and is something over which an architect has some amount of control.

(insert Figure 5 here)

Figure 5. Skin Loads for a Summer Design Day for the Figure 3 Building with and without Thermal Mass.

The final portion of the first homework assignment asks the students to convert their one-zone model of the building in question to a nine-zone model. The goal here is to see that the sum of all nine zones results in the same prediction as the single zone model. This result provides a bridge for discussing reasons for defining single vs. multiple zone models and how HVAC systems can impact these decisions.

The second homework problem is more conceptual and thought provoking. The first part is a comparison of cooling control strategies with and without night and weekend setback. While the results are not unexpected, the students are forced to contemplate when heating and cooling should be available and the impact that decision has on energy consumption and peak thermal loads. In most cases, when heating or cooling is always available, the total energy consumption increases while the peak thermal load decreases. Using setback increases overall energy efficiency, but results in higher peak thermal loads and thus larger equipment, ducts, etc. This can lead into discussions about alternative ways of providing low-energy heating or cooling during setback hours.

The second portion of the second homework problem is a series of alternatives on the original building. In these alternatives, the students formulate how they expect the cooling loads to change as modifications are made to the building and then either prove or disprove their theories with simulation results. The alternatives investigated include: the addition of insulation to the exterior walls, a switch to double pane tinted windows from single pane windows, the use of overhangs rather than altering the window type, and a reorientation of the building by rotating it 45 degrees counterclockwise. Sample results are shown in Figure 6.

(insert Figure 6 here)

Figure 6. Thermal Loads for Typical Summer Design Day Conditions for the Southwest Zone of the Figure 3 Building.

Most of the results shown in Figure 6 are what the students expected to see based on the intuition they developed from lecture material. The double pane tinted window reduces the cooling loads because it reflects much more of the solar energy coming in through the windows on the south and west exterior walls. Using overhangs rather than switching to double pane tinted windows has a similar effect but does not quite perform as well since the sun is lower in the sky during the late afternoon hours, reducing the effectiveness of the overhang over the west-facing window. The rotated case where the building is shifted 45 degrees counterclockwise results in windows that face southeast and southwest, leading to greater solar gains during much of the day.

Most students view the results for the alternative where insulation is added with surprise. The expectation is that adding insulation will reduce thermal heat gain from the outside and thus should result in a lower cooling load. Indeed, this would certainly be the case with a heating load since the addition of insulation will increase the R-value of the walls and thus reduce heat losses through the exterior walls. However, the situation in the summer is more complex. The heat generated inside the zone by people, lights, and equipment tends to be the largest portion of the cooling load. Some of this energy is stored in the walls during the daytime. At night, as the temperature drops, much of this stored energy “leaks” to the outside. With the added insulation, this natural process is hindered and more of the energy from internal gains is actually felt inside the zone. Such a counter-intuitive example makes a good argument for analyzing annual simulation results to obtain a true picture of potential energy savings and the shortcomings of hand calculations that would not have captured this effect.

Conclusions

The above discussion shows that even with a fairly limited amount of thermal simulation computer work that some important goals can be met without a significant alteration of an introductory HVAC course outline. While such an addition to an existing course cannot replace a semester long class in thermal simulation, it can provide students with several important lessons. These include a reinforcement of concepts heard in formal lectures,

an appreciation for the fundamentals of thermal physics, experience with thermal simulation software, and the first steps toward the development of thermal intuition. While all of these goals are important in their own right, the overriding goal is to leave the students with knowledge and simulation capabilities that they can apply in their studio projects. This allows the student to go beyond technical concepts of an HVAC class and begin to understand how to integrate energy concerns into their studio projects and future designs as professionals.

Acknowledgments

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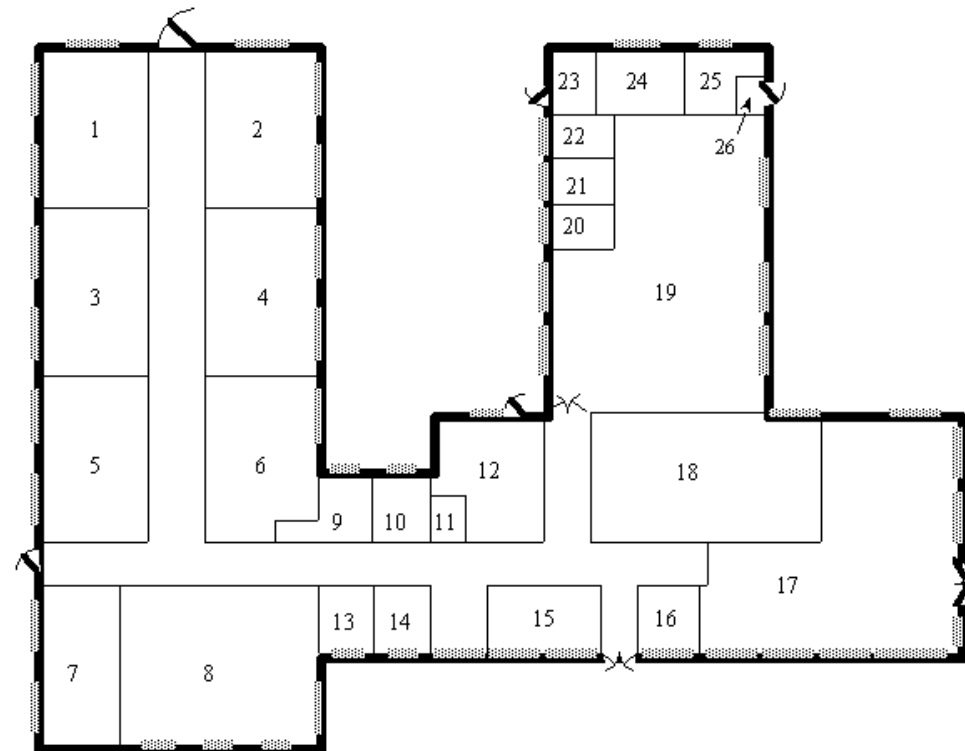


Figure 1. Fort Monmouth Education Center (BLAST Support Office).

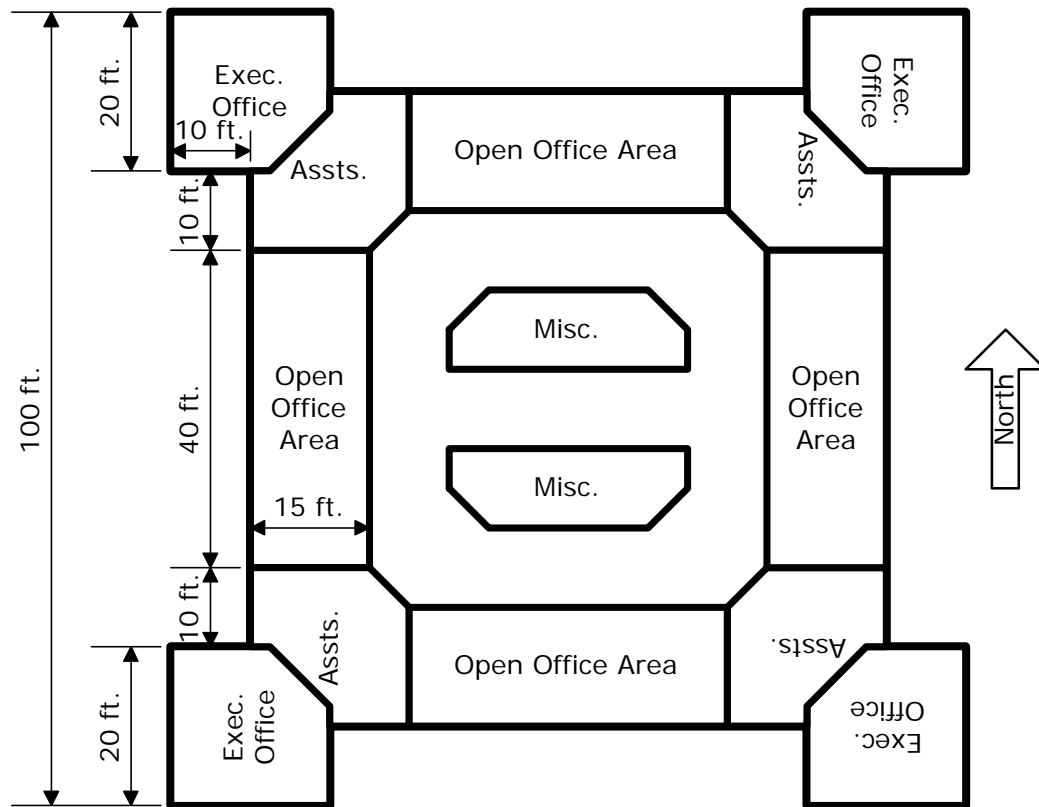


Figure 2. Fictional Multi-Story Office Building with Articulated Exterior.

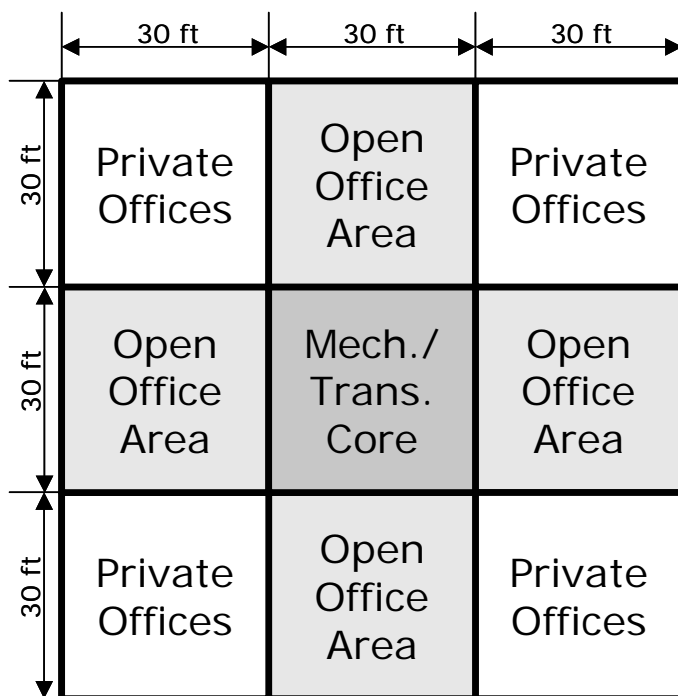


Figure 3. Fictional Multi-Story Office Building with "Rubic's Cube" Floor Plan.

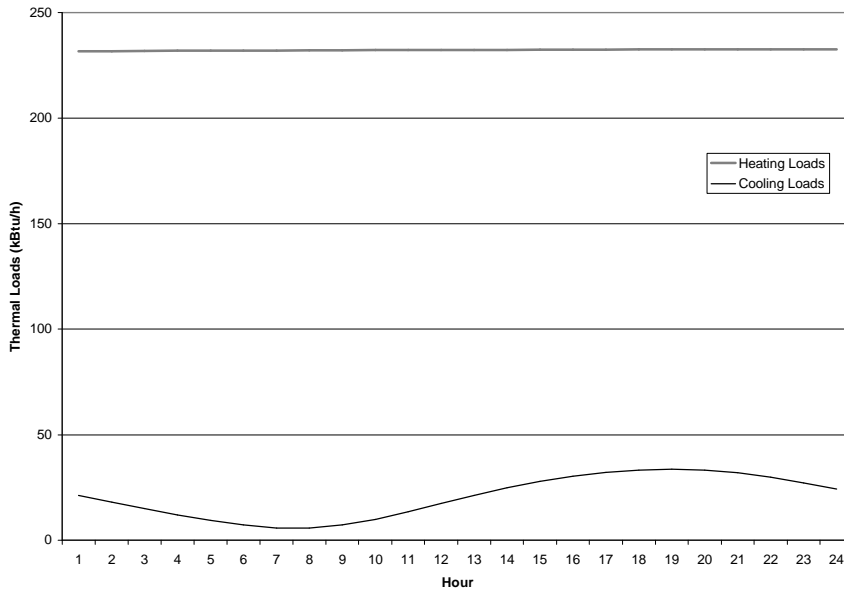


Figure 4. Skin Loads for Winter and Summer Design Days for the Figure 3 Building.

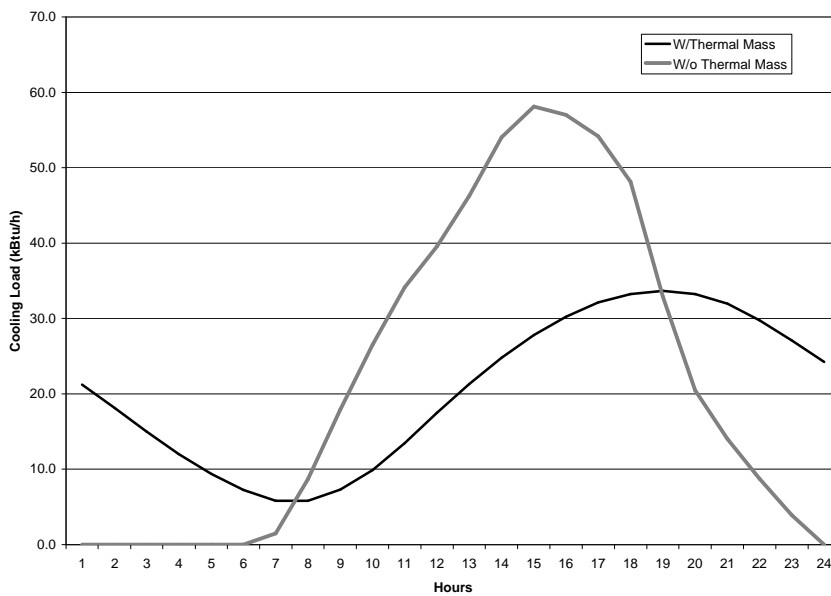


Figure 5. Skin Loads for a Summer Design Day for the Figure 3 Building with and without Thermal Mass.

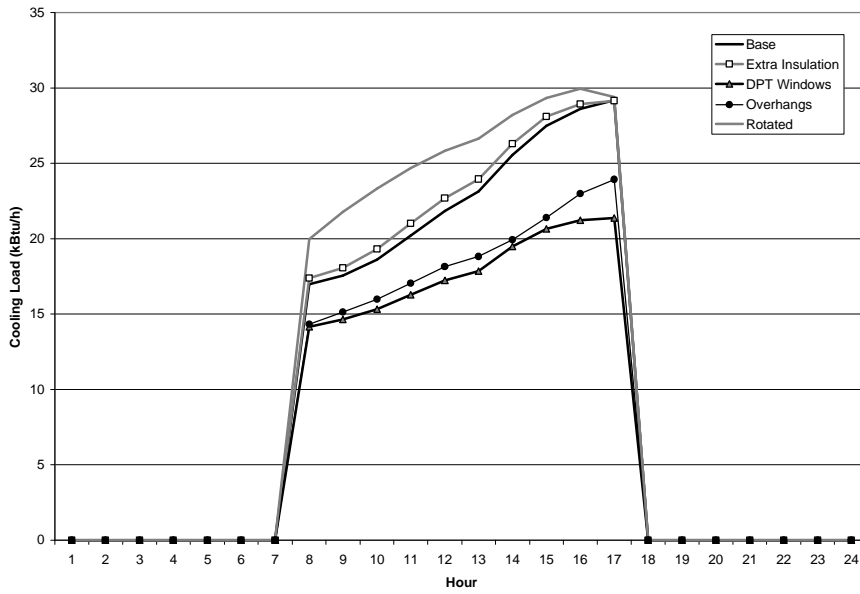


Figure 6. Thermal Loads for Typical Summer Design Day Conditions for the Southwest Zone of the Figure 3 Building.